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Multiplet Relocation in a Heavy Oil Field Using the Double Difference Method

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Summary

The uncertainty in microseismic event locations can be reduced using the Double Difference method. Multiplet groups are first identified via waveform cross correlation, then relocated using all available P- and S-wave picks. We illustrate the robustness of the procedure on field and synthetic data examples. In the field data, two event clusters, each surrounding a different well are linked by a chain of events suggesting possible stress communication. Both clusters are tightened and completely separated following event relocation; eliminating stress communication. Multiplet analysis is also suitable for post-processing quality control of event locations by examining separation distances between events with near-identical waveforms that should be collocated.

Introduction

Microseismic monitoring provides indirect information about the subsurface by mapping the location and magnitude of brittle failure events. The uncertainty in microseismic event locations may exceed the size of the feature being imaged. We address the aforementioned issue using multiplet analysis. A doublet is a pair of events produced by the same source mechanism in the same location; a multiplet is a group of three or more events with a common source and hypocenter. The waveforms corresponding to two events in a doublet should be nearly identical except for additive random noise. We identify multiplets using the cross correlation method of Arrowsmith and Eisner (2006). Once identified, multiplets can be relocated as a group to improve location accuracy (Rubin et al. 1983). Historically, multiplet analysis has had other applications including modeling temporal variations in crustal velocity (Poupinet et al. 1984). We relocate multiplets using the Double Difference method (Waldhauser and Ellsworth, 2000).

Method and Examples

We cross correlate waveforms from every event with waveforms from every other event. If the correlation coefficient for a pair of events exceedes a certain threshold, that pair of events is considered a doublet. The threshold is determined based on the signal to noise ratio of the data (Arrowsmith and Eisner 2006). Doublets are linked in a chain-like fashion to form multiplet groups. Figure 1 shows a multiplet group.

The Double Difference method uses predicted travel time, t^p, and observed travel time, t, residuals for event pairs to compute event location corrections. The travel time residual, dr_{ij}, for events i and j is calculated as . Event location corrections, Δx_i, Δy_i, Δz_i, and ΔT_i, are then computed as $\frac{\partial t_i}{\partial x}\Delta x_i + \frac{\partial t_i}{\partial y}\Delta y_i + \frac{\partial t_i}{\partial z}\Delta z_i + \Delta T_i - \frac{\partial t_j}{\partial x}\Delta x_j - \frac{\partial t_j}{\partial y}\Delta y_j - \frac{\partial t_j}{\partial z}\Delta$. By considering the difference in travel times between two events, the errors introduced by any unmodeled velocity anomalies between source and receiver should be mitigated. That is, assuming the events being relocated are close to each other relative to the source-receiver separation. Due to the aforementioned assumption, the Double Difference method is well suited to multiplet relocation.

A map of the multiplets in the field data is shown in Figure 2. Two large event clusters can be seen at 250 m depth and 450 m depth. The events in Figure 2 are the multiplets before relocation. The multiplets after relocation are shown in Figure 3. The link between the clusters present in Figure 2, is absent in Figure 3; suggesting that there is no stress communication between clusters. The large shift in event locations seen going from Figure 2 to Figure 3 suggests significant location error. This postulate is supported by the presence of events in the top right area of Figure 4; a cross plot of event pair correlation coefficient versus hypocenter separation. Events with nearly identical waveforms should be of common origin and thus located closely in space.

Conclusions

Multiplet analysis can provide highly accurate relative event locations by mitigating the effects of unmodeled velocity anomalies. Relocation facilitates interpretation by tightening diffuse clouds of events. Crossplotting correlation coefficient versus hypocenter separation for every pair of events presents a quality control as highly correlated event waveforms should be of common origin thus their hypocenters should be separated by a small distance.

Acknowledgements

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References

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Rubin, Gillard, and Got, 1998, A reinterpretation of seismicity associated with the January 1983 dike intrusion at Kilauea Volcano, Hawaii, *Journal of Geophysical Research*, **103**, 10003-10015

Waldhauser F. and Ellsworth W. L., 2000, A Double-Difference Earthquake Location Algorithm: Method and Application to the Northern Hayward Fault, California, *Bull. Seis. Soc. Am.,* **90**, 1353-1368

Figures

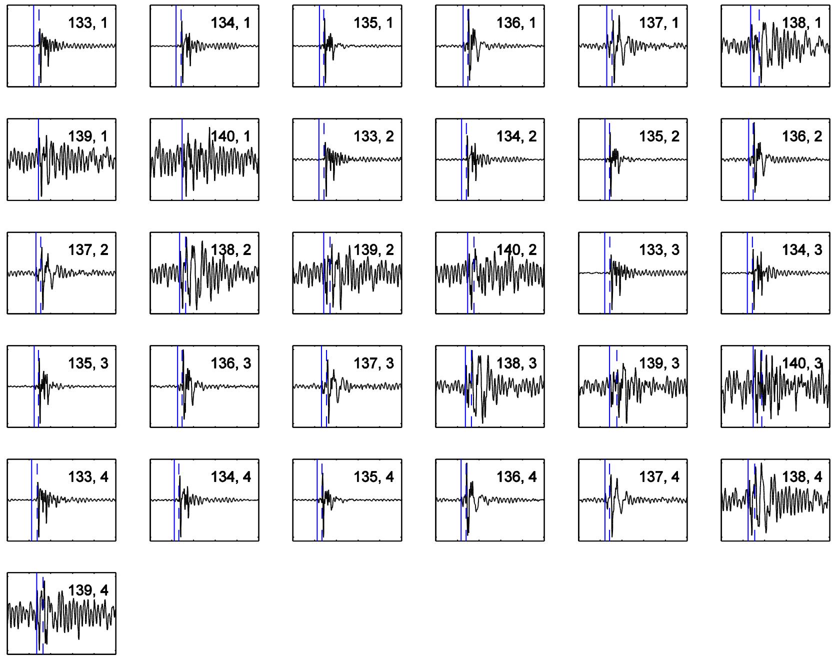

Figure 1 – Normalized waveforms for a multiplet group containing 4 events. Only the vertical component is shown for clarity. Each event has a correlation coefficient of 0.85 or higher with at least 1 other event. Every event is linked to every other event either directly or in a chain-like fashion through a series of directly linked events. Top right corners shows station number followed by event number for each recording. P wave and S wave picks are shown as a solid and dashed line respectively.

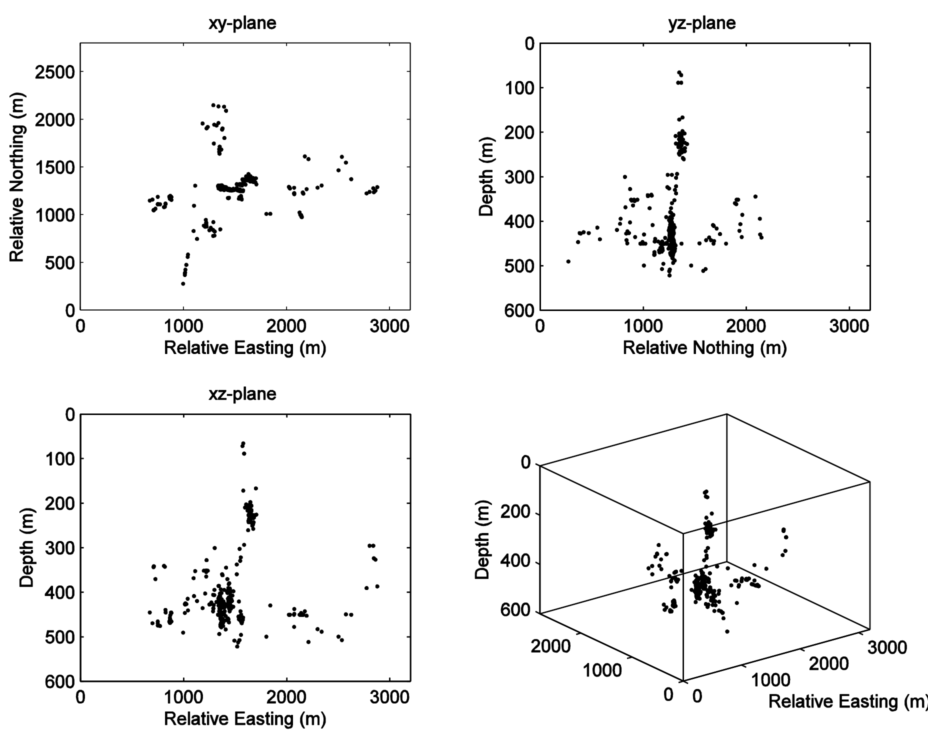

Figure 2 – Microseismic multiplets before relocation shown in four different perspectives. Note the chain of events between 250 m and 350 m depth apparently linking two large event clusters.

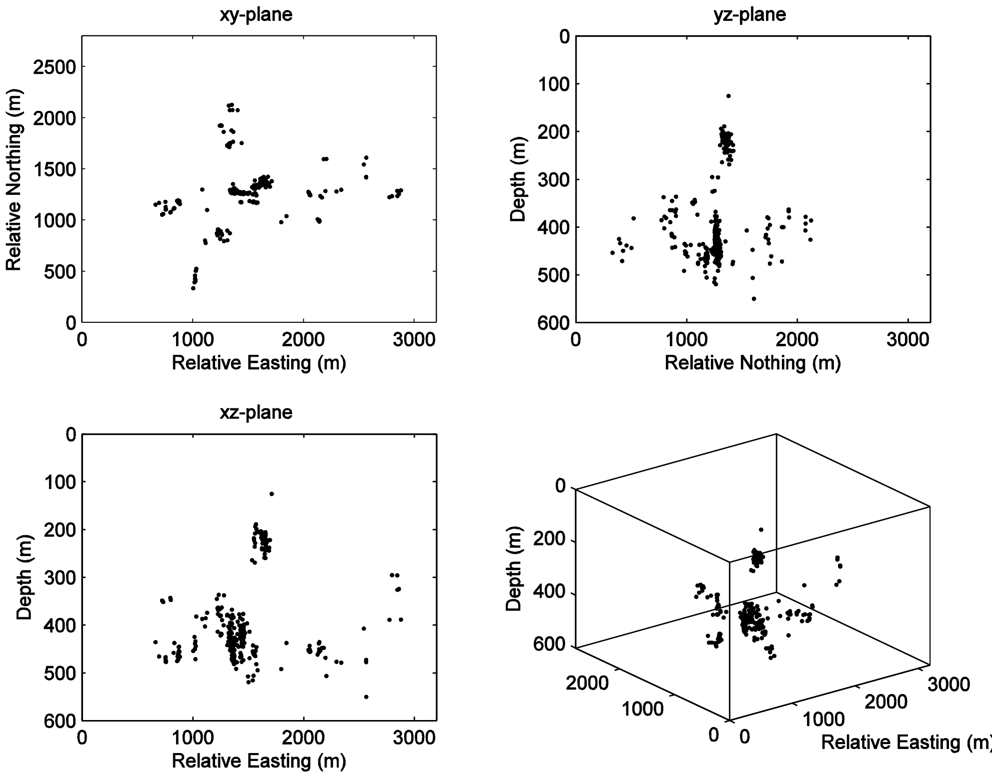

Figure 3 – Microseismic multiplets after relocation shown in four different perspectives. Note the two large event clusters are completely separate.

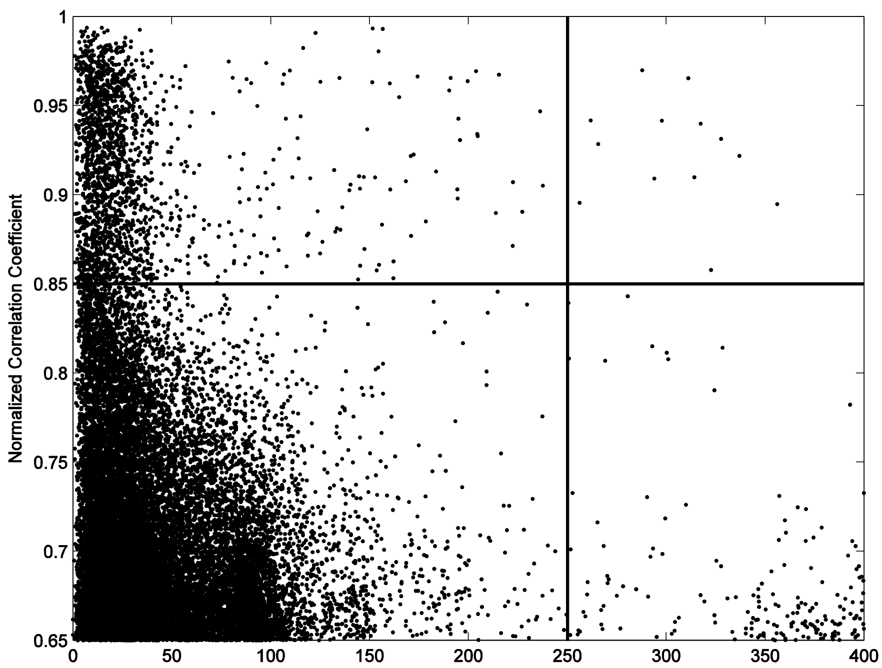

Figure 4 – Crossplot of waveform correlation coefficient versus hypocenter separation distance. Every pair of events is compared. Data points in the top right area of the plot with a strong correlation and a large hypocenter separation suggest large event location errors.